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IMPROVING THE PROTECTION OF 330KV TRANSMISSION LINE AGAINST TRANSIENT INSTABILITY USING INTELLIGENT SOLID STATE RELAY

[1]Ogbuagu C., [2]Alor M.O., [3]Ugwu K.I.

[1,2,3] Department of Electrical and Electronic Engineering Faculty of Engineering Enugu State University of Science and Technology (ESUT) Enugu, Nigeria

Email: [1]cifeanyi144@gmail.com

ABSTRACT

This paper presents improving the protection of 330KV transmission line against transient instability using an intelligent solid state-based protection scheme'. Sustained faults have been identified as one of the major causes of transient instabilities in power networks. The longer a fault current stays in a power network, the more vulnerable the network will be to transient instability. One key important method of protecting a transmission line against transient instability is by reducing the time it takes the transmission line protection scheme to identify and resolve a fault or isolate the faulty section of the line. In this paper, the existing electromechanical protection scheme is replaced with an intelligent solid state-based protection scheme that recognizes faulty conditions early enough and isolates faulty sections of the line with a higher speed. This protection scheme was realized using Artificial Neural Network (ANN) and Silicon Controlled Rectifier (SCR). The developed scheme was simulated on the Simulink platform and the results shows that the proposed intelligent solid state-based protection scheme not only improved the protection of the test network by shortening the clearing time from 0.02 seconds to 0.01 seconds but also detects faults early enough before it causes any harm hence ensuring a well protected system.

Keywords: Transient, Instability, Protection, SCR, ANN, Faults, Simulink, Transmission lines.

1. INTRODUCTION

The voltage instability of power supply Nigeria is very alarming. The economy of our country is seriously affected. From year, 2000 to 2010 the collapse of the power system was on the rise resulting in unreliable and insecure power systems in the whole country (Aliyu et al, 2013). These goes with incessant tripping of lines, load shedding and most times out right blackout. In the year 1993, nineteen out right system collapse that lead to faults and power failure in Nigeria were recorded. According (Aliyu et al, 2013) the year 2003 recorded the highest number of rate of power system collapse. The Nigeria government lost an estimated amount of one billion naira yearly (2.5% of GDP) as a result of resultant energy outages resulting from voltage collapse (Ali, 2014). A lot of industries closed down within the period as a result of frequent system collapse which made them to spend much money on running diesel generators. Mostly affected by this menace of voltage instability of the Nigeria power system are small businesses and heavy machinery manufacturers and users. More so, the whole population is equally affected socially, psychologically and physically because of insufficient and unreliable energy supply. So far the lowest record of voltage collapse in the Nigerian power system was in the year 1992, the year has a single record of system collapse which at the same time is partial i.e. not complete collapse.

Sometimes the damage caused by these instabilities in homes, organizations and industries are very enormous. So many small scale industries have closed due to the damage the instability has caused them on their equipments. Apart from the equipment and device damages, instability in power supply has made some manufacturers that cannot cope with alternative power supply to close production. The list of the problems is endless.

2. THEORY OF WORK

From research, one of the major causes of instability is the use of mechanical relays in the protection of the power system lines. With the mechanical relays when fault occurs it takes these relays a long time to report the fault resulting in lots of damage being done to the system before protection is implemented (Abhishek, 2018).

Protective relay functions as sensing device that senses fault, and determines its location and finally sends tripping command to the circuit breaker (Moshtagh et al 2018). The circuit breaker after getting the tripping command from the protective relay disconnects the affected element and thus protects the system from damages. But most times the mechanical relays in use report the fault after much damage has been done on the system.

One of the main disadvantages of an electromechanical relay (EMR) is that it is a mechanical device, with moving parts that has low switching speed (response time) due to physical movement of the metal contacts working with magnetic fields. Over a period of time these moving parts wears out and fail (Claude& Shannon, 2015).

Sustained faults have also been identified as another cause of transient instabilities in power networks, the longer a fault current stays in a power network, the more vulnerable the network will be to transient instability. If due to slow switching of electromechanical based protection scheme, a fault results into transient instability, unscheduled outage will occur and this will impact negatively on all the stake holders in the power value chain (Dalstein & Kulicke, 2015). Incessant and prolonged outages occasioned by transient instability will reduce standard of living of the people and reduce national productivity.

To provide a good protection to the transmission network against transient instability so as to avoid outages and low productivity, this research proposes an intelligent solid state based protection scheme fast reporting of faults and reduction of the switching time of the protection scheme. As the name suggests a solid-state relay (SSR) is an electronic device that switches on or off when a minute external voltage is impressed on its control terminals (Wikipedia, 2018). A solid-state relay has no mechanical path.

An Artificial Neural Network (ANN) controller will be used to provide intelligence for early monitoring of faults while an arrangement of solid state thryristors will provide a swifter switching response devoid of delays.

The proposed system monitors the line constantly and it also has the capacity to detect when the line condition is tending towards having a fault. The scheme ensures that fault will not affect the line and will also restore the system when transiency clears. Hence minor faults that should not cause unnecessary tripping and faults that could cause serious damage will be shielded from the system.

3. MATERIALS AND METHOD

3.1 Materials

Nigeria 42 bus 330KV transmission Bus and Line Data

The grid line and bus data are the basic inputs needed to perform load flow studies on the network of study as shown in table1.

Power System Analysis Toolbox (PSAT)

Load flow on the 330kV transmission line of the network of study was done with the help of PSAT.

Laptop Computer

The Simulink platform used to carry out all experimentations in this work was developed in the laptop. The Laptop was also used in compiling this report.

Other Components

Generator, load, electromechanical relay, circuit breaker, transmission line, bus bar, scopes, etc.

3.2 METHOD AND SYSTEM MODELING

3.2.1 Data Collection

The data for network including the existing protection scheme of the test network was collated using PSAT at Delta-Aladja 330KV transmission station. The data collection considered transmission line parameters as identified in Newton Rapshon load flow analysis algorithm in Abhishek (2018) and was used for the system development.

3.2.2 Transmission line model

Three phase transmission was modeled using the Clarke's transformation model. This models the transmission line considering relationship between the phase self inductance, line to line mutual inductance and resistance, line to line capacitance and line to ground capacitance. To simply unify this power characters, the Clarke transformation model was adopted (Tavares et al., 1998).

$$V_1 - V_2 = \begin{bmatrix} R-R_m & 0 & 0 \\ 0 & R-R_m & 0 \\ 0 & 0 & R-R_m \end{bmatrix} I_i + \begin{bmatrix} L+2M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix} \frac{dI_i}{dt} \qquad 1.0$$

$$I_1 + I_2 = \begin{bmatrix} C_g & 0 & 0 \\ 0 & C_g + 3C_i & 0 \\ 0 & 0 & C_g + 3C_i \end{bmatrix} \frac{dV_2}{dt} \qquad 2.0$$

Where: $I_1 = TI_1$, $I_2 = TI_2$, $V_1 = TV_1$, $V_2 = TV_2$

$$T = \frac{1}{\sqrt{3}} \begin{bmatrix} 1 & \sqrt{2} & 0 \\ 1 & \frac{-1}{\sqrt{2}} & \sqrt{\frac{3}{2}} \\ 1 & \frac{-1}{\sqrt{2}} & -\sqrt{\frac{3}{2}} \end{bmatrix} \qquad 3.0$$

Where: *R* is the line resistance for the segment; R_m is the mutual resistance for the segment; *L* is the line inductance for the segment; C_g is the line-ground capacitance for the segment; C_l is the line-line capacitance for the segment; *T* is the Clarke's transformation matrix; *I1* is the three-phase current flowing into the ~1 port; *I2* is the three-phase current flowing into the ~2 port; *V1* is the three-phase voltage at the ~1 port; *V2* is the three-phase voltage at the ~2 port; The positive and zero-sequence parameters are defined by the diagonal terms in the transformed equations as:

$R_0=R+2R_m$; $R_1=R-R_m$

$L_0=L+2M$; $L_1=L-M$

$C_0=C_g$; $C_1=C_g+3C_l$

Rearranging these equations gives the physical quantities in terms of positive and zero-sequence parameters:

$R = 2R^1 + R^0 3$, $R_m=R^0 + R^1 3$, $L = 2L^1 + L^0 3$, $M = L^0 + L^1 3$; $C_l=C^1 + C^0 3$, $C_g=C_0$

3.2.3 The Silicon Controlled Rectified (SCR) relay

SCR is a four layered semi conductor device which can control the flow of current and voltage. For the optimized switching action two SCR were arranged back-to-back with their source pins tied together as a TRIAC. Their drain pins are connected to either side of the output. The substrate diodes are alternately reversing biased to block current when the relay is off. When the relay is on, the common source is always riding on the instantaneous signal level and both gates are biased positive relative to the source by the photo-diode as shown in figure 1;

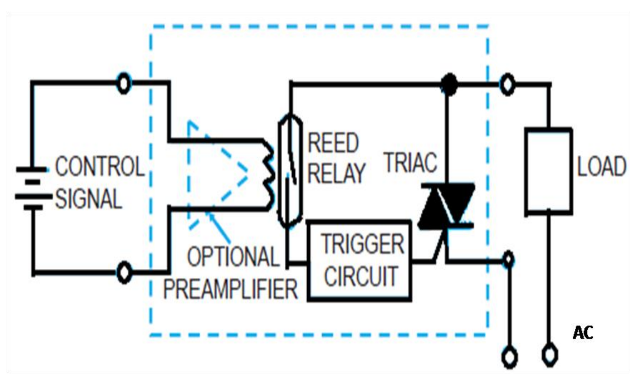

Figure 1: block diagram of the SCR

The figure 1 showed the block diagram of the SCR relay showing how the fault current from the load was identified by the TRIAC and used to protect the load. For more information on the SCR relay see (Mbunwe et al., 2018). However the limitation of the SCR relay is the lack of intelligence to fault current detection. When the fault current does not reach the programmed fault level for the relay, it will not protect the network,

3.2.4 Development of the ANN

ANN is one out of the numerous machine learning algorithms which can learn and make accurate decisions. The ANN model was adopted from Yadav and Thoke (2011) which is made up of interconnected neurons, bias, tansign activation function as shown in the figure 2;

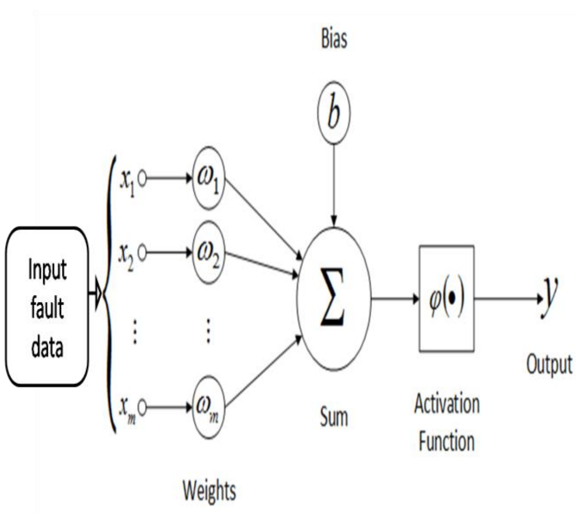

Figure 2: ANN modeling diagram

The figure 2 showed the model of the neural network architecture which was used to control the triggering action of the SCR.

also the need for instantaneous triggering when fault occurred cannot be satisfied by the SCR relay as it suffer delay time as identified in (ClaudE, 2007). Hence there is need for an intelligent SCR relay for the protection of the network.

3.2.5 Training of ANN Controller to be used to monitor the line

To develop the ANN controller in Simulink, the training data was first obtained from simulation of the test network during normal operating conditions (no fault) and during fault condition. The three phase voltage values (Vabc) at Delta bus during normal operation condition are recorded likewise the voltage values during fault condition. The obtained voltage values are normalized by making all the data points non negative and then obtaining the sum of Va, Vb and Vc for each data point. This sum forms the input data. The target of the ANN is the firing angles required by the SSR to either isolate the faulty section (during fault) or to take no action (when no fault exist). A firing angle of 180 degrees will make the relay/breaker to isolate the faulty section while a firing angle of 0^{o}will cause the relay to take no action. The target is therefore a single column of data obtained by assigning zero degree against normalized voltage values obtained without fault and 180 degree to normalized voltage values obtained during fault condition. The idea is to train the ANN controller to output zero when no fault exist in the network and 180 when there exist a fault. Series of training dataset used for developing the ANN controller were generated.

The ANN user interface in Simulink will help the ANN fitting application to be launched in Simulink environment. The input and target data are then loaded. On accepting the input and target data, the system creates the network and prompts the user for training. The structure of the created ANN controller is shown in Figure 3 The After a successful training, the developed ANN controller is converted into a Simulink model and the development script generated. Simulink model of the developed ANN is as shown in Figure 3. Series of ANN training script were also generated. The mean square error plot and the regression plot showing the performance of the process of the ANN training, validation and testing were all discussed in the result section, while the result of the training which presented the intelligent algorithm was presented in figure 4;

structure shows that the ANN controller has one input and one target with ten hidden layers. Levenberg-Marcquardt training algorithm adopted from (Yadav and Thoke, 2011) is selected and used to train the network.

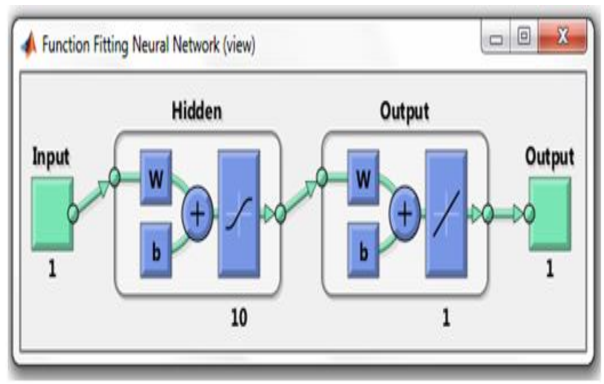

Figure 3: Structure of the developed ANN controller

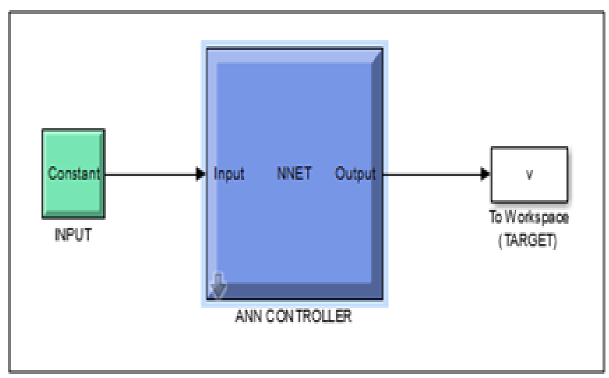

Figure 4: Simulink model of the developed ANN controller

3.2.6 Development of the intelligent SCR relay

The longer time taken by electromechanical based relay and circuit breaker as will be seen from characterization result to disconnect the detected fault allows fault current to stay longer than needed in the transmission line. This situation helps to sustain transient stability in the system. To reduce this switching time so as to reduce the time taken by the protection system to remove any detected fault from the system, a Solid state based relay protection scheme is proposed in this work. The switching speed of the protection scheme ensures that the fault component is quickly removed from the system so as to restore transient stability as fast as possible. The Simulink model of the intelligent Solid State Relay (SSR) was presented as figure 5;

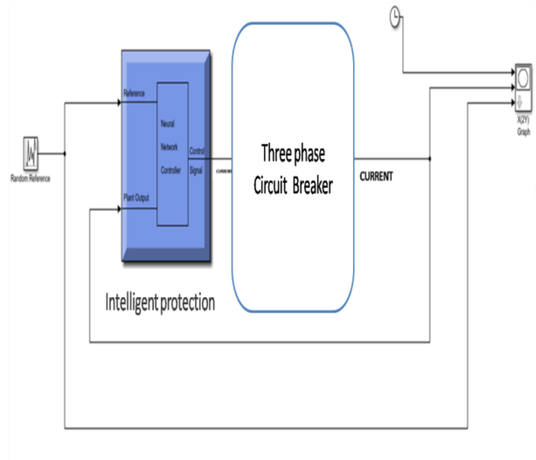

Figure 5: Simulink model of the proposed

Figure 5 presents the modeled intelligent Solid State based scheme for protection against transient instability in the test network. The neural network controller was connected to the three phase circuit breakers to protect the transmission lines against fault as shown in the Simulink in figure 6;

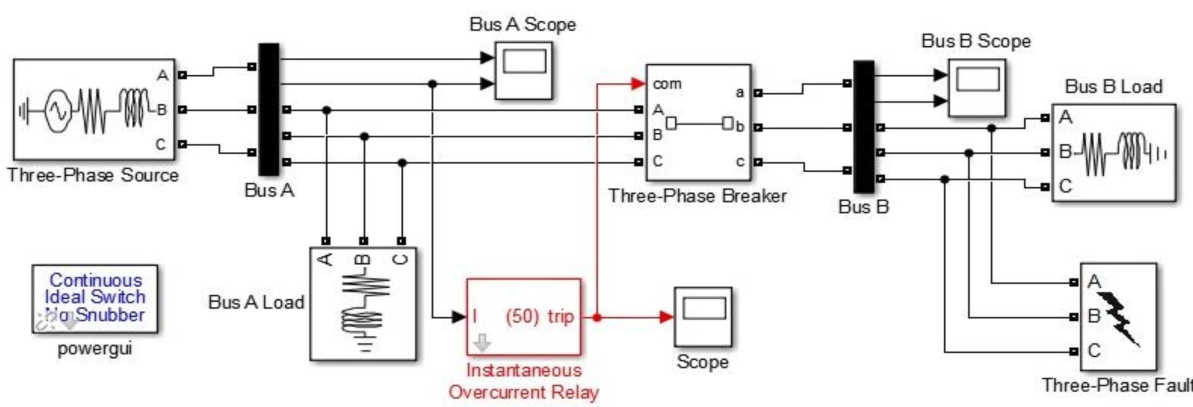

Figure 6: Simulink model of the proposed

The model of Figure 6 is connected with the fault block configured three phase fault model in

Warlyani (2011) to introduce a fault in the network at 0.4secs and simulated with the parameters in table 1. As shown in figure 6 the protection scheme is composed of the neural network controller, a solid state relay/breaker system and a fault block, all connected to the earlier developed Simulink model of the test network. The work of the neural network controller is to monitor the network buses for any abnormal signal (current/voltage). On detecting any abnormal signal due to fault, the ANN controller will supply signals with the right firing angle to disconnect the faulty part of the system as quickly as possible to ensure that network is effectively protected against transient instability. On receiving the signal with the right firing angle, the solid state relay/circuit breaker instantly switches into blocking mode thereby blocking the faulty part of the network.

Table 1: Parameters and variables of the test transmission line (Delta-Aladja)

	Line length	30km
1	Line impedance	0.0011+ j0.0088pu
2	Load on Aladja Bus	1.82 + j0.67pu
3	Power Supplied from Delta Bus	1.0742 + j0.10895 pu
4	Voltage level	330kV

4. RESULTS AND DISCUSSIONS

4.1. ANN TrainingResults and Discussions

The mean square error plot and the regression plots were used to assess the performance of the training, validation and testing of the developed ANN control model. Figures 7 and 8 present the mean square plot and the regression plots respectively for the ANN.

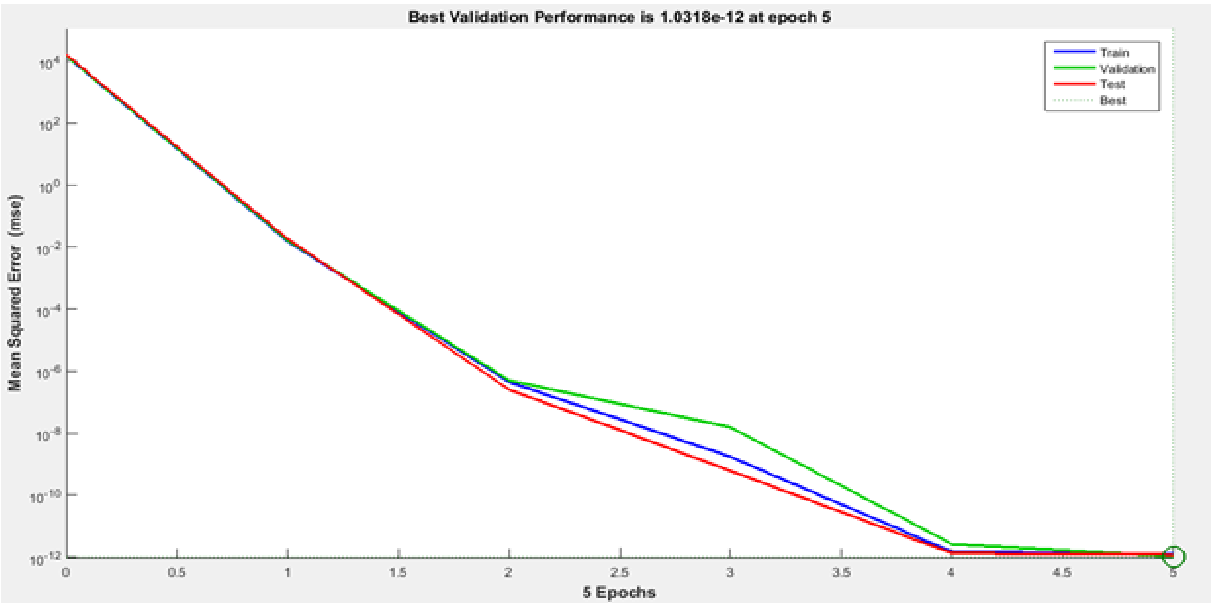

Figure 7: Means square error plot for ANN training, Validation and testing

The MSE performance of the neural network showed that during the training, only 1.0318e-12 error was achieved at epoch 5. The implication is that the training was perfect the neural network correctly learn the fault data trained. The regression is presented in figure 8;

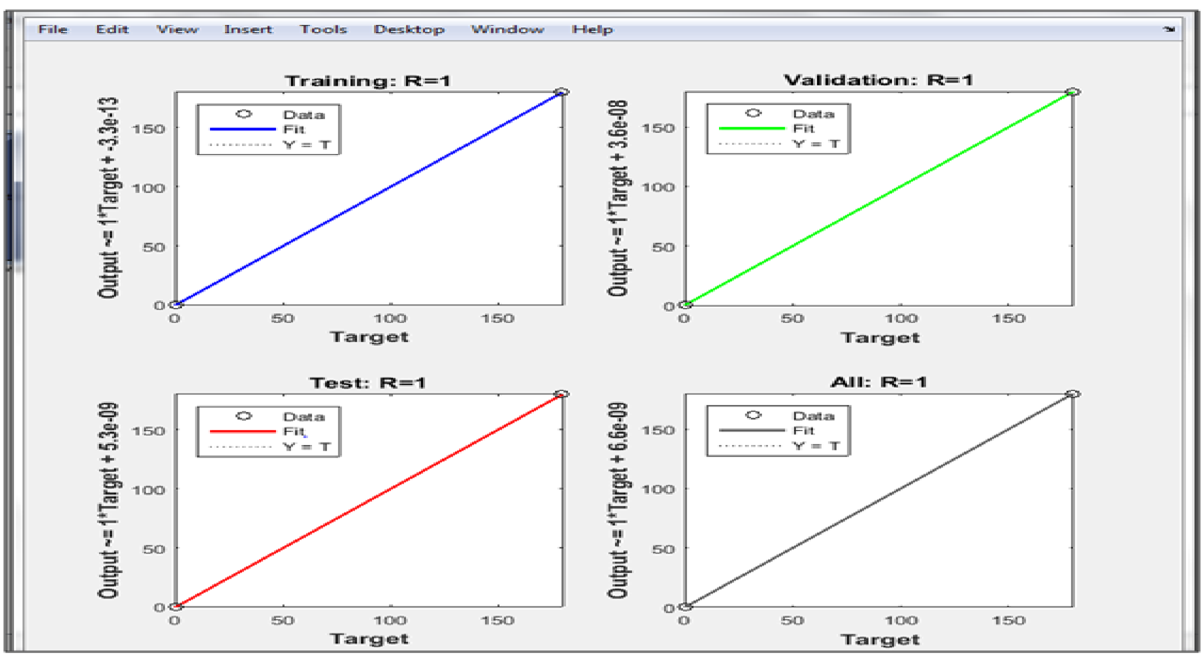

Figure 8: Regression result

Figure 8 showed the R value of one perfect mapping of inputs to targets during training, validation and testing. The implication of these results is that the generation of the correct firing angle for controlling the network against faults and transient instability.

4.2 Result of simuation with fault and intelligent solid state relay

The section presented the result of the simualiton of the power system network under fault consition and with the intelligent potection system as in figure 9;

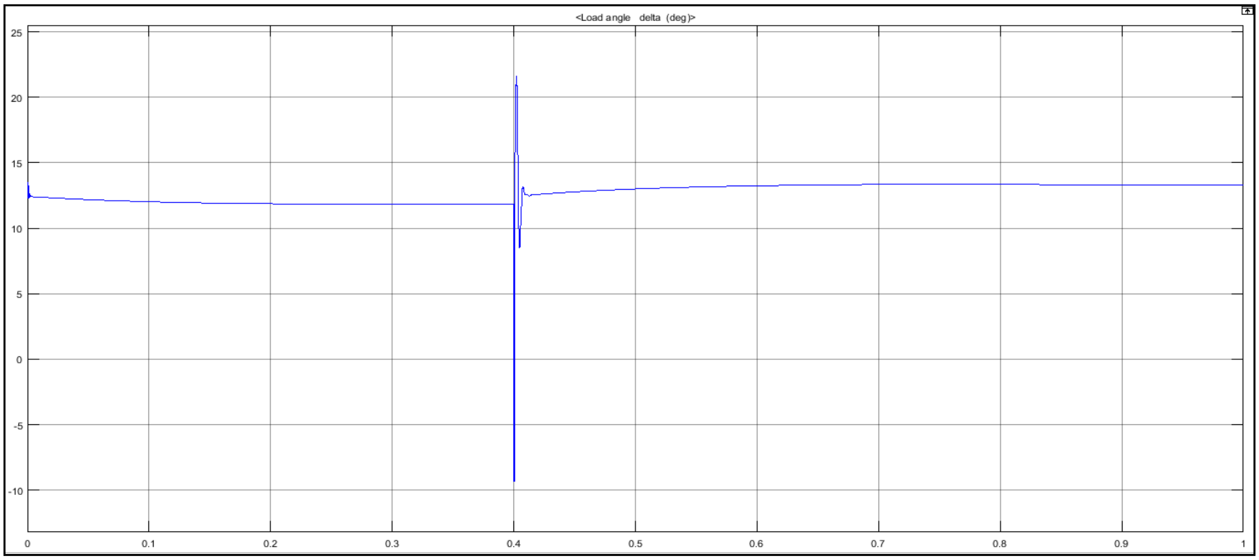

Figure 9: Improved Load angle response of the Generator at Aladja bus.

This result shows that the proposed protection scheme responded and isolated the faulty in just 0.01s. This translates to 50% reduction in fault clearing time and 50% improvement in protection against transient instability. Also the post disturbance signal with the proposed scheme was free of ripple as against the existing scheme were the post disturbance signal had ripple of short amplitude. Between 0 and 0.4secs (no fault situation) the ANN controller produced zero firing angle that made relay/breaker to take no action. However, as soon as the three phase fault is introduced at 0.4secs, the ANN controller generated a firing angle of 180 degrees to put the relay/breaker in a blocking mode that isolated the fault block. The swift disconnection of the fault block restored stability to the network.

4.3 Result of simuation with fault and no intelligent solid state relay

This section presented the result of the power syste network proteciton without the intelligent relay but mechnical relay as in figure 10;

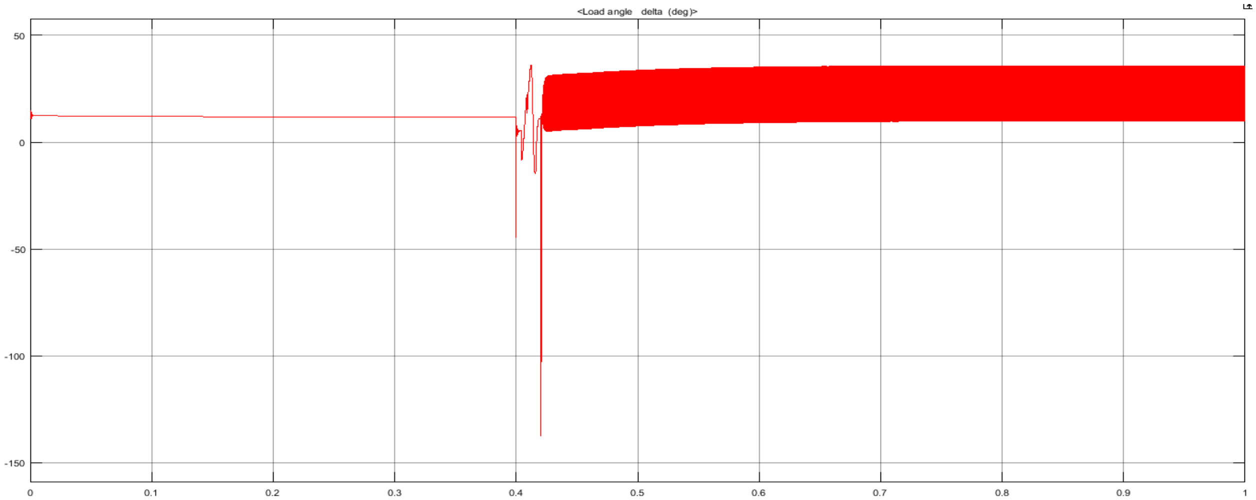

Figure 10: The characterised Load angle response of the Generator at Aladja bus.

Figure 10 shows the load angle response obtained when the existing protection system was used to isolate a three phase fault introduced in the network at 0.4 seconds. It can also be shown from Figure 10 that the protection system restored the system back to transient stability at 0.42 seconds (after 0.02 seconds). The result also slowed the presence of ripples in the signal after restoration to stability. The comparative response perforance to fault with the intelligent relay and without is presented in the figure 11;

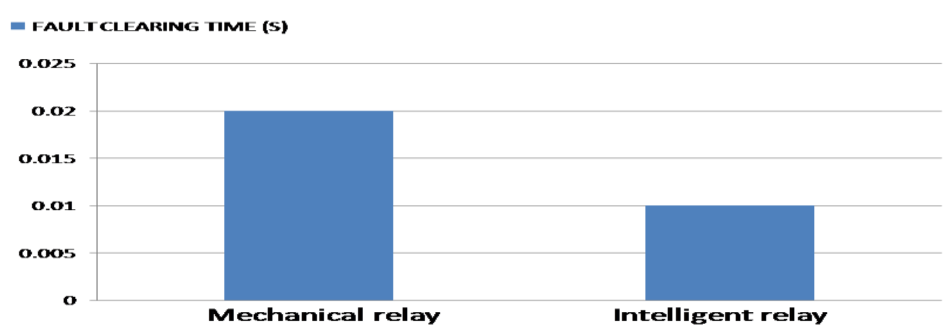

Figure 11: Bar chart showing Comparative fault clearing time

The result in figure 11 showed that the intelligent relay was able to respond faster to fault when compared to the mechnical relay. The reason was due to the ability of the neural network to intleigently classify fault current on the line and then the SCR fires to active the breaker for protection.

5. CONCLUSION

From the above results, it's evident and can be concluded that the solid state based intelligent protection scheme by reducing the fault clearing time from 0.02s to 0.01s, the scheme improved the test network protection against transient instability by 50% and additionally was able to recognize a faulty condition before its manifestation making the scheme a unique one from what has been existing

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